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MEMORANDUM

From: Bill Jemison
To: Dr. Daniel Tam, ONR
Date: 8/29/2011

Subject: ULI Progress Report 001–Advanced Digital Signal Processing for Hybrid Lidar
FY11 Progress Report (6/1/2011– 8/29/2011)

This document provides a progress report on the project "Advanced Digital Signal Processing for Hybrid Lidar" covering the period of 6/1/2011–8/29/2011.

cc. Dr. Linda Mullen

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FY11 Progress Report: ULI - Advanced Digital Signal Processing for Hybrid Lidar

This document contains a **Progress Summary for FY11** and a **Short Work Statement for FY12**.

Progress Summary for FY11

This ULI project was started on June 1st, 2011. The 1 technical objective of this project is the development and evaluation of various digital signal processing (DSP) algorithms that will significantly enhance hybrid lidar performance. Other objectives include determining the processing requirements for each algorithm such that the feasibility of hardware implementation can be assessed and the suitability of the algorithms for various lidar applications can be determined. The ULI student selected for the project is Mr. Paul Perez, a Ph.D. student at Clarkson University.

The progress for this period consists of the work performed by Mr. Perez during his ten week NREIP experience at NAWC and additional investigations into software defined radio hardware performed at Clarkson University. Each will be briefly described below.

Mr. Perez's NAWC Work - Mr. Perez participated in the ULI program review held at the Penn State Applied Physics Laboratory (APL) on June 7th and 8th. Given that this project had only started a week prior to the review, Mr. Perez's briefing focused on the project objectives. Mr. Perez then spent ten weeks at the Naval Air Warfare Center in Patuxent River, MD, working with his Navy mentor, Dr. Linda Mullen, under the NREIP program. His primary efforts focused on replacing hybrid lidar analog signal processing components with digital components for a proximity detector application.

The general approach is shown in figure 1. The analog RF source was replaced with a direct digital synthesizer and the analog IQ detector was replaced with a digital demodulator.
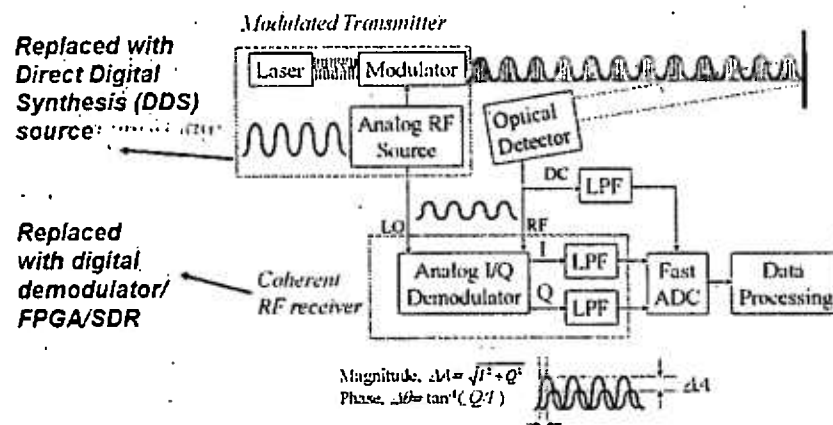

Figure 1. The hybrid lidar analog source was replaced with a DDS source and the analog IQ detector was replaced with a digital demodulator.

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The Navy's experimental set-up is shown in figure 2 and it uses modules manufactured by COMBLOCK for the signal processing hardware..
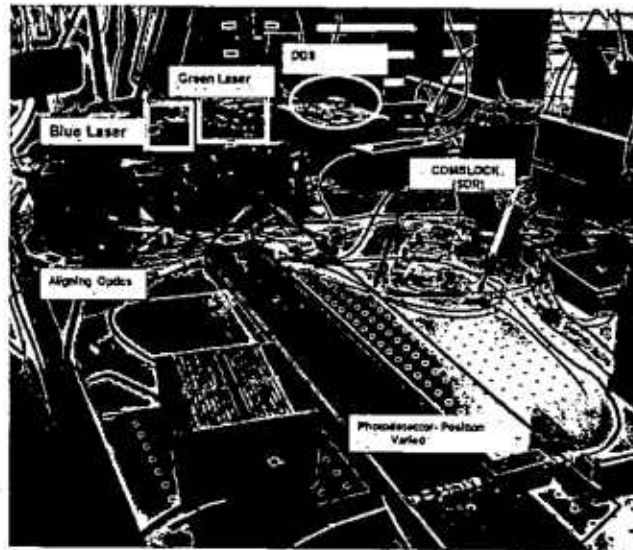

Figure 2. Experimental set-up at NAWC. COMBLOCK modules were used for the signal processing

Mr. Perez assisted with air experiments to detect range using both a blue and green laser. Experimental results were presented to ONR on August 3rd at NAWC by Mr. Perez.

Software Defined Radio Investigations – NAWC is using a digital hardware platform based on COMBLOCK software defined radio (SDR) modules. These products provide the designer with a modular hardware platform that allows various signal processing functions to be implemented in separate "blocks". These blocks may be cascaded together to achieve a desired "software defined radio" (SDR) function. NAWC has indicated that, based on their experience, a reasonable amount of low-level hardware and FPGA knowledge is required to use the COMBLOCK modules effectively. Clarkson has investigated several other SDR approaches which include two open source SDR platforms and one commercial platforms. The products investigated include GNU Radio, OSSIE, and Signalhound. One of the objectives of investigating these alternatives is to see if we can identify an approach that minimizes the need for low-level hardware knowledge which may lead to a faster development.

Open source software is an attractive option for the hybrid lidar SDR approach. GNU radio is an open source SDR platform that received much attention several years ago. It interfaces to a Universal Software Radio Peripheral (USRP) that is available commercially. GNU radio is written in Python, a high-level scripting language. We downloaded and installed GNU radio and were able run several examples. There are numerous SDR functions available for use within GNU radio; however, the

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documentation for these functions is minimal (or has been removed). We believe that GNU radio was recently purchased by National Instruments. The support for GNU radio appears to be frozen and despite all the attention it received, we have decided to refrain from pursuing this approach. We do not believe that GNU radio is a sustainable design platform at this time. However, we will watch for SDR product announcements from National Instruments.

OSSIE is another open source SDR project which also interfaces to the USRP. It is developed by Virginia Tech under National Science Foundation support. The Naval Postgraduate School has written some laboratory assignments using OSSIE and there are several corporate sponsors listed on the OSSIE web page. There are only a few SDR functions available for OSSIE at the current time. We were able to download OSSIE and run several example programs. However, the support of OSSIE hinges on the continued support of Virgina Tech by the NSF and, therefore, we believe that OSSIE is not a sustainable design platform at this time.

Signalhound is a commercially available software defined radio (SDR) receiver. Signalhound is marketed primarily as a cost-effective spectrum analyzer which operates from 1Hz to over 4.4 GHz and costs under $1000. Signalhound provides spectrum analysis software with the product. The Signalhound and the Signalhound spectrum analysis software is shown in Figure 3. Signalhound also comes with an Application Programmer's Interface or API that allows a user to control the device and directly access IQ data from C language API commands. The API is available in Windows and Linux versions. We have been able to configure the Signalhoud through the API and are currently able to control the real-time streaming of IQ data. A sample of IQ data is shown in Figure 4. We are currently trying to invoke the Signalhound API calls from within a real-time MATLAB environment. MATLAB is a powerful high-level programming language that has a variety of signal processing toolboxes. Control of the Signalhound from a real-time MATLAB program would present a convenient and powerful design environment. Transmitter functions are not supported by Signalhound; however, and we are currently looking at ways to implement them.
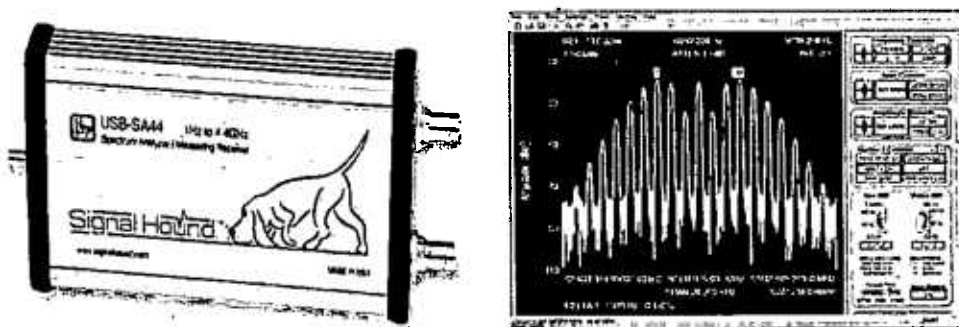

Figure 3.. Signalhound SDR receiver and spectrum analysis software

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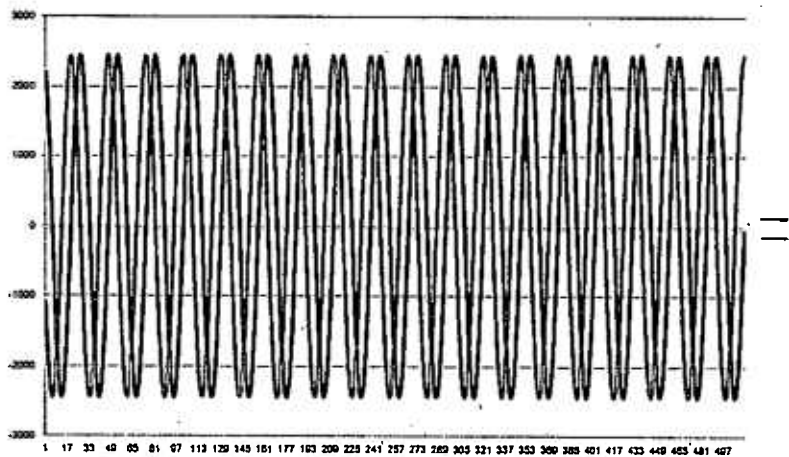315-268-6509, Fax 315-268-7600, wjemison@clarkson.edu

Figure 4. Real-time IQ data from the Signalhound API. Data can be obtained with simple programming calls.

Summary – This project started in June 2011. Thus far our focus has been on gaining experience with several SDR design environments. Mr. Perez gained experience with COMBLOCK modules for a proximity detector experiment and we have investigated several other SDR alternatives. We now have sufficient hardware experience to proceed to investigating the various signal processing algorithms in FY12 that were proposed in the original proposal.

Budget and Schedule:
The period of performance is June 1st 2011 through May 31st 2014. Mr. Perez's research assistant appointment started on June 26th, 2011 and runs through June 23rd, 2012. The first 75K increment of funding will carry us through June 23rd, 2012. We anticipate that approximately $26,000 will be spent by the end of the government fiscal year (Sept. 30th 2011).

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Advanced Digital Signal Processing for Hybrid Lidar
Short Work Statement for FY2012

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Short Work Statement for FY2012

In FY2012 we plan to continue the work that was originally proposed. Specifically, we plan to finalize our SDR tradeoff study in the next month in order to select a hardware platform for our algorithm investigations. Several preliminary high-level algorithm approaches described in the original proposal will be investigated. We plan to investigate these via a combination of simulation and experimentation. We will develop our own simulations for transmitter and receiver functions and will use the underwater channel simulator developed by the Navy on another program to include optical propagation effects. Techniques that will be studied include:

1. *Pulse compression lidar waveforms* – Pulse compression is used on virtually every radar system to improve system sensitivity and range resolution simultaneously. Linear FM, non-linear FM, and Barker Codes are all types of common radar pulse compression techniques. Much of the previous work in hybrid lidar-radar focused on the use of a continuous wave (CW) RF signal. The Navy is currently investigating the use of modulated pulse waveforms. Extensions of this work based on advanced radar pulse compression techniques will be explored.

2. *Adaptive Integration for Turbid Conditions* – The hybrid lidar-radar approach exploits the decorrelation properties of scattered light. While the target return maintains its RF coherence and appears at the RF carrier frequency at the lidar photoreceiver output, the backscatter and forward scatter signal components decorrelate and appear at lower frequencies. This phenomena, which allows increased system sensitivity through frequency discrimination of the desired target return from the undesired scattered light, was the basis for the hybrid lidar approach. Backscatter suppression improvements on the order of 20 dB were obtained using coherent detection, an analog signal processing technique. The fundamental sensitivity of an analog signal processing approach is determined by the signal to noise ratio (SNR) of the photodetector output at the RF carrier frequency. A positive SNR (usually on the order of 6dB) is required for the minimum detectable signal (MDS).

It is well known in radar that DSP can be used to provide integration gain that allows analog signals with negative SNR to be detected. Integration gains in excess of 20 dB are easily obtained. The limit to the integration gain that can be achieved is related to the coherence time of the target signal and the system scanning requirements. In radar the coherence time is determined primarily by the phase noise of the transmitter. In hybrid lidar the coherence time (and potential integration gain) will be determined by a combination of the phase noise of the RF signal modulating the laser and the decorrelation properties of the optical scattering. It is expected that the coherence time will be a strong function of the water

turbidity and the laser wavelength. These dependencies will be investigated to determine the coherence time as a function of optical wavelength and water turbidity. This will determine the optimum integration time. Various methods to determine an optimum integration time adaptively in real time are also possible using estimation techniques to determine turbidity when the wavelength is known.

3. *Multi-wavelength data fusion* – The Navy is investigating the effect of the optical wavelength on system sensitivity and ranging as a function of water turbidity. One approach is to select a single wavelength based on the measured or estimated turbidity. An alternate approach is to use well-known data fusion algorithms to combine the lidar returns from the transmission of simultaneous wavelengths. This would simplify the multi-wavelength transmitter architecture while providing an optimum sensitivity for the wavelengths selected.

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